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Toxicity Evaluations for Hazardous Waste Sites
An Ecological Assessment Perspective

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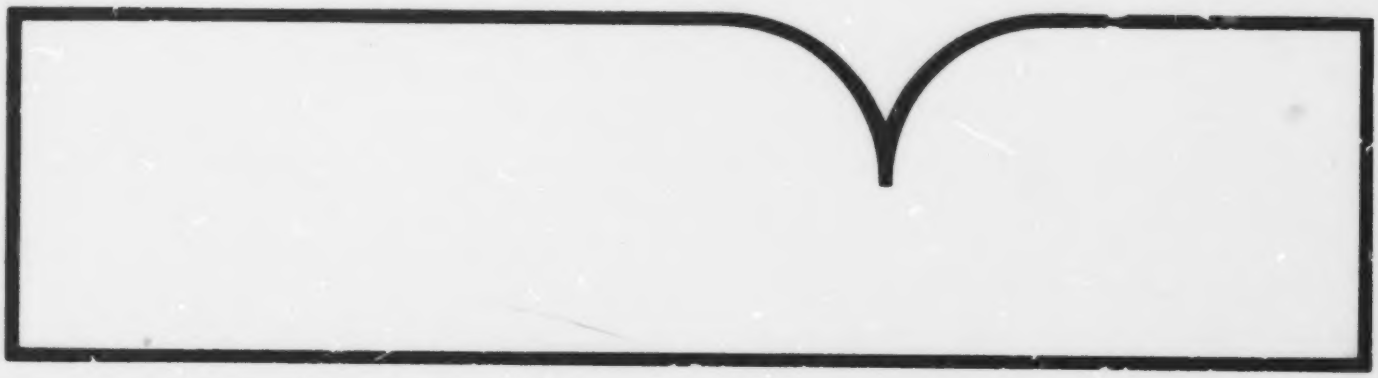

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16. ABSTRACT

Ecological assessments for hazardous waste sites should include acute toxicity tests as well as short-term tests which measure biological endpoints other than death. Toxicity and field assessment methods may be assembled into "tool boxes" which reflect not only the site-specific demands made by the ecological assessment process, but the continuing progress in methods development. Toxicity assessment tools may yield information regarding acute biological responses elicited by site-samples as well as suggest longer-term biological effects (e.g., genotoxicity or teratogenicity) potentially associated with subacute and chronic exposures to complex chemical mixtures characteristic of hazardous waste sites. Toxicity tests, however, are but one component of an ecological assessment for a hazardous waste site; field components must be given equal regard during the early phases of site evaluation. This becomes particularly important when field sampling is considered, since integration of toxicity assessments (be those in situ or laboratory-generated) and field assessments requires a well-designed sample plan to establish linkages among toxicity, site-sample chemistry and adverse ecological effects, if apparent. Spatial statistic techniques like kriging are finding increased applications in linking toxicity with other elements of site-evaluation (e.g.,field-sample chemistry). Through kriging, for example, areal distributions for site-specific toxicity and chemistry data sets may be derived, then "maps" of site-sample toxicity and chemistries overlaid. Patterns of coincidence apparent in these distributions may then suggest linkages among toxicity, site-contaminants, and adverse ecological effects.

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TOXICITY EVALUATIONS FOR HAZARDOUS WASTE SITES: AN ECOLOGICAL ASSESSMENT PERSPECTIVE

Greg Linder[1], Joseph C. Greene[2], Larry Kapustka[2], Cathy L. Bartels[1], Michael Bollman[1], Kevin DeWhitt[1], Waunda Baune[1], Julius Nwosu[1], Sheila Smith[1], David Wilborn[1], and Jennifer Miller[1].

[1]NSI Technology Services Corporation, Environmental Research Laboratory, 200 S.W. 35th Street, Corvallis, OR. 97333.

[2]U.S. Environmental Protection Agency, Environmental Research Laboratory, 200 S.W. 35th Street, Corvallis, OR. 97333.

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ABSTRACT

Ecological assessments for hazardous waste sites should include acute toxicity tests as well as short-term tests which measure biological endpoints other than death. Toxicity and field assessment methods may be assembled into "tool boxes" which reflect not only the site-specific demands made by the ecological assessment process, but the continuing progress in methods development. Toxicity assessment tools may yield information regarding acute biological responses elicited by site-samples as well as suggest longer-term biological effects (e.g., genotoxicity or teratogenicity) potentially associated with subacute and chronic exposures to complex chemical mixtures characteristic of hazardous waste sites. Toxicity tests, however, are but one component of an ecological assessment for a hazardous waste site; field components must be given equal regard during the early phases of site evaluation. This becomes particularly important when field sampling is considered, since integration of toxicity assessments (be those in situ or laboratory-generated) and field assessments requires a well-designed sample plan to establish linkages among toxicity, site-sample chemistry and adverse ecological effects, if apparent. Spatial statistic techniques like kriging are finding increased applications in linking toxicity with other elements of site-evaluation (e.g., field-sample chemistry). Through kriging, for example, areal distributions for site-specific toxicity and chemistry data sets may be derived, then "maps" of site-sample toxicity and chemistries overlaid. Patterns of coincidence apparent in these distributions may then suggest linkages among toxicity, site-contaminants, and adverse ecological effects.

INTRODUCTION: Approaches to Ecological Assessment

Ecological assessments for hazardous waste sites have recently gained increased attention after the passage of the Superfund Amendments and Reauthorization Act of 1986 (SARA). As a result, US EPA has drafted numerous guidance documents which suggest approaches to the evaluation of adverse ecological effects which may exist at hazardous waste sites (US EPA 1988a; US EPA 1989; Warren-Hicks, et al. 1989); the application of ecological assessment techniques has become an integral part of the remedial investigation/feasibility study

process, and in general ecological assessments have assumed a greater role in site assessment.

Ecological assessments at hazardous waste sites may require various methodologies which reflect the site-specific demands required by waste sites. Ecologically based hazard assessments may be considered as integrated evaluations of effects which are attained through site measurements of toxicity and exposure completed in both laboratory and field. As complex functions, toxicity and exposure integrations may yield an estimate of hazard associated with any particular waste site (Figure 1).

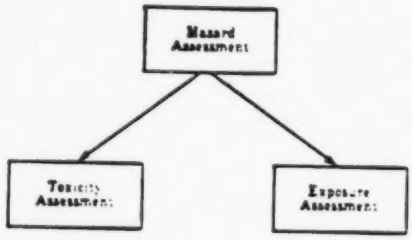

Figure 1. Toxicity and exposure assessments within the hazard evaluation process.

Toxicity assessments are derived from acute tests as well as subacute and chronic tests which measure biological endpoints other than death. Generally, these toxicity assessments are derived from laboratory-generated data. Exposure assessments within an ecological context frequently rely upon field methods which measure ecological endpoints, either on-site or at reference sites, and yield survey data relevant to estimates of adverse ecological effects associated with a waste site.

Both toxicity and field assessment methods may be compiled into "tool boxes" (Kapustka and Linder 1989). Depending upon the environmental matrix being tested, site-specific toxicity assessments may be derived using tests selected from these "tool boxes" (Horning and Weber 1985; Peltier and Weber 1985; Weber, et al. 1988; Greene, et al. 1988), which may include invertebrate and vertebrate, algal, plant, and microbial test systems (Figure 2). These toxicity assessment tools may yield information regarding acute biological responses elicited by site-samples or their derivatives, and may suggest longer-term biological effects (e.g., genotoxicity or teratogenicity) potentially associated with subacute and chronic exposures to complex chemical mixtures characteristic of hazardous waste sites. Potential contaminant migration as well as soil attenuation of contaminant effects may also be evaluated using these toxicity assessment tools, if eluates are prepared and tested in the laboratory. In situ toxicity assessments, while not as well developed as laboratory toxicity tests, are becoming more prominent in the ecological assessment process

(Warren-Hicks, et al. 1989; Murphy and Kapustka 1989), especially since in situ methods infer a linkage between toxicity and exposure functions, and reduce the problems associated with lab-to-field extrapolations of toxicity data.

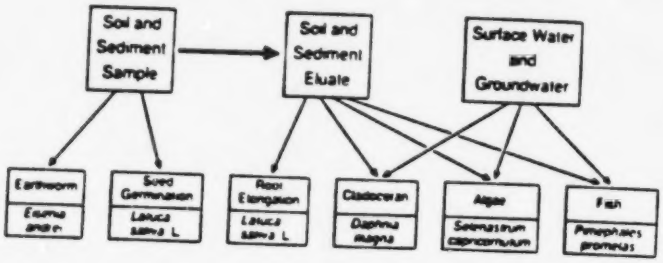

Figure 2. Test profiles useful in toxicity evaluations for ecological assessments may include representative organisms amenable to direct and indirect tests on site-samples.

Toxicity tests, however, are but one component of an ecological assessment for a hazardous waste site; field components must be given equal regard during the early phases of site evaluation. This becomes particularly important when field sampling is considered, since integration of toxicity assessments (be those in situ or laboratory-generated) and field assessments requires a well-designed sample plan to establish linkages among toxicity, site-sample chemistry and adverse ecological effects, if apparent. Ecological methods applicable to hazardous waste site evaluations are varied, and reflect the diversity apparent in waste sites which occur in a variety of geographic settings. Depending upon the environmental setting (aquatic or terrestrial) and the site-specific questions being asked in the evaluation process, methods have been collected into ecological assessment "tool boxes" (e.g., LaPoint and Fairchild 1989; Kapustka 1989; McBee 1989; Bromensnenk 1989) which provide a source of techniques available for ecological site assessments.

Spatial statistic techniques like kriging may be applied to site assessment and help establish linkages between toxicity and other components of site-evaluation (e.g., field-sample chemistry or field surveys). Kriging is a tool borrowed from geostatistics which may help integrate site-specific measures of toxicity and chemistry derived from site-samples. For example, site-soil samples may be evaluated for their toxicity potential through bioassays which evaluate soil eluates (e.g., algal or invertebrate short-term toxicity tests), then eluate chemistries (e.g., routine eluate chemistry) may be completed for these same site-samples. Through kriging, areal distributions for these site-specific toxicity and chemistry data sets may be derived, then "maps" of site-sample toxicity and chemistries developed. Coincidence patterns among these spatial distributions may subsequently suggest linkages among toxicity, contaminants, and adverse ecological effects.

To illustrate these techniques available in the ecological assessment "tool box," a hazardous waste site case study will be outlined briefly and the integration of site-sample chemistry and toxicity data will be summarized spatially.

WASTE SITE CASE STUDY

The Drake Chemical Superfund site[1] in Pennsylvania covers approximately eight acres, and consists of landfills, various lined and unlined treatment lagoons, and a dry unlined "canal" lagoon. Historic records indicate that chemical intermediates for dyes, pharmaceuticals, and cosmetics manufacturing were produced at the site. Also, various intermediates for the herbicide and pesticide industry were produced, including 2,3,6-trichlorophenylacetic acid (and its intermediates), which was the major contaminant found within the site boundaries and at some distance from the source.

Stratigraphically, much of the site consists of an overburden comprised of sludge and contaminated soil lenses, with unconsolidated materials ranging from near-surface sandy silts and clays to near-bedrock coarse sands and gravels. Bedrock is characteristically composed of fractured shales and varies in depth depending upon site location. An "erosional channel" may exist, but has not been clearly delineated. Groundwater occurs in the unconsolidated materials, with the water table being consistently maintained at a depth of 10 to 15 feet. Perched water lenses are not infrequent, and occur in associations with the clays and silts characteristic of near-surface formations. Hydraulic conductivities and flow velocities indicate that movement of groundwater through the unconsolidated materials occurs at 3.5 to 20 feet per year. Surface waters near the site consist of two rivers. The site, however, is bermed by road and railroad embankments. Historically, the site has been inundated by floodwater, but under normal conditions the runoff is contained within the site boundary where it percolates into the soil or directly enters the on-site leachate lagoon as surface runoff. Topographically, the leachate lagoon is the low point on-site. Various landscape constructions have been completed during the site's history, including a French drain and various catch basins designed to direct surface drainage into one of the bordering creeks.

METHODS AND MATERIALS

Site-samples received. Site-samples were obtained through an on-site contractor from locations (surface and below surface sample sites, 40 sites x 3 depths plus eight additional samples) identified in Figure 3. All site-soils were stored

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[1]case study based on waste site assessment completed in conjunction with US EPA regional staff.

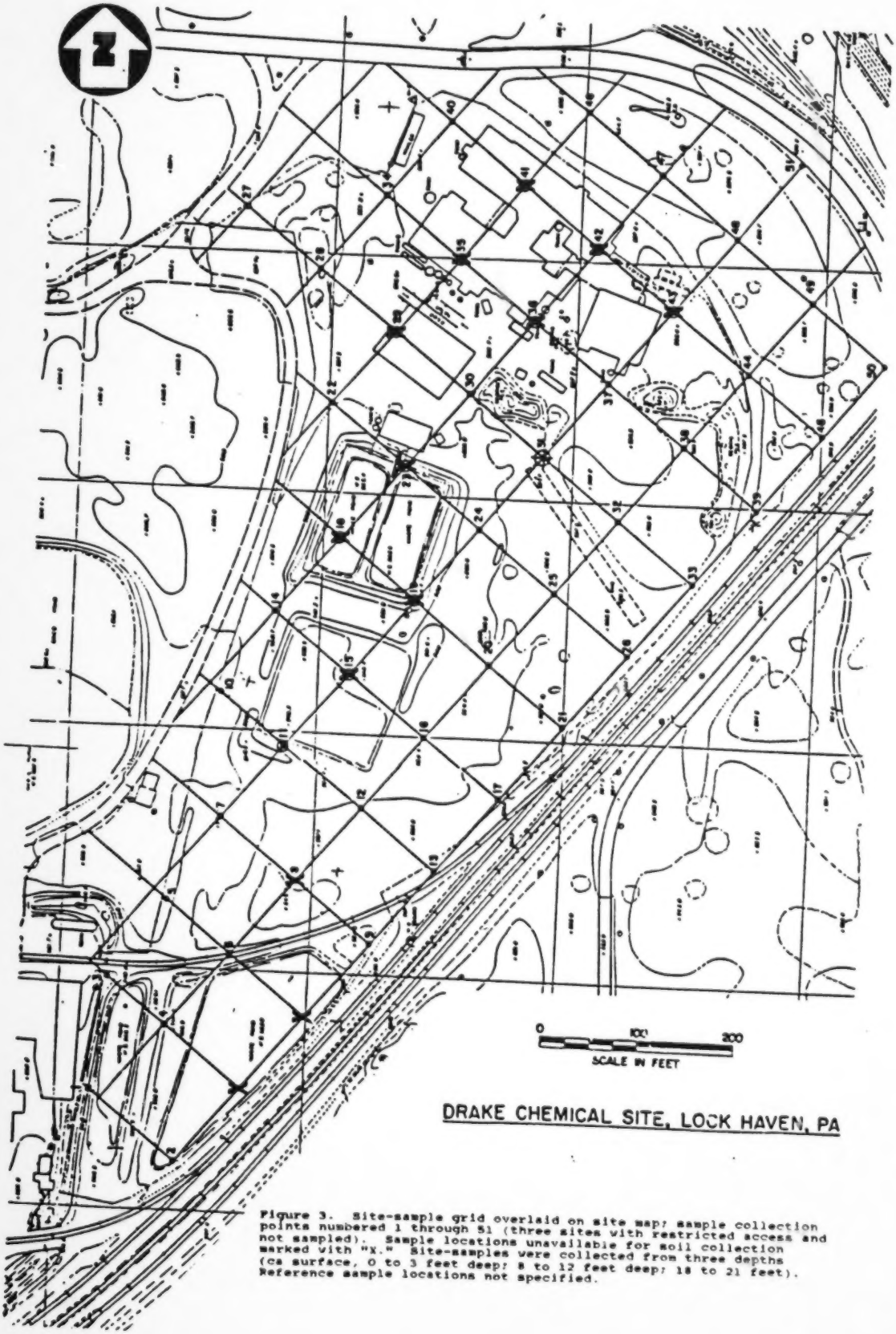

Figure 3. Site-sample grid overlaid on site map; sample collection points numbered 1 through 51 (three sites with restricted access and not sampled). Sample locations unavailable for soil collection marked with "X." Site-samples were collected from three depths (ca surface, 0 to 3 feet deep; 8 to 12 feet deep; 18 to 21 feet). Reference sample locations not specified.

at 4°C until soil processing and in-lab toxicity tests were initiated.

Eluate preparations from site-soils. No direct toxicity tests on soils (see Figure 2) were completed for the samples received from the site, but eluates were prepared from untreated site-soils to evaluate the potential mobility of chemical constituents which were present in the soil samples. Upon receipt, soil samples were screened through a 1/4" soil sieve, then eluted. Screened site-samples were mixed with four volumes eluent (deionized water) per gram dry weight site-soil or sediment. The slurry was then mixed in complete darkness for 48 hours at 20 +/- 2°C. After mixing, the resulting eluate was centrifuged, then filtered through a 0.45 um cellulose acetate or glass fiber filter. Eluate preparation incorporated original sample moisture content into its preparation and hence, a constant "solute/solvent" ratio was assured during the extraction of any site-sample. The filtered eluates were subsequently evaluated with an appropriate aquatic test system such as the algae (Selenastrum capricornutum) or macroinvertebrate (Daphnia magna) toxicity test.

Toxicity assessment tools: Indirect tests on soil eluates. A short-term chronic, Selenastrum capricornutum 96-hour toxicity test was conducted on soil eluates, and yielded toxicity estimates for soil contaminants which were potentially mobile owing to their water solubility. In the algal bioassay, growth in test concentrations which was less than that in controls indicated inhibitory effects during the 96-hour exposure; stimulation was indicated if growth in exposed systems was greater than growth in concurrent controls. Briefly, in the test algae were exposed to known concentrations of soil eluate. Algal cells were inoculated into test flasks which contained known concentrations of soil eluate, then were incubated for 96 hours in environmental chambers held at 24 +/- 2°C and 4304 +/- 430 lux (continuous light). The typical algal bioassay included a range of test concentrations capable of yielding EC_{50} data (effective concentrations which yield 50% reduction in algal growth relative to controls after 96 hours), as well as subculturing information pertinent to the evaluation of lethality. Cell counts performed on electronic particle counters yielded algal biomass estimates based upon cell counts and mean cell volumes. Evaluations of 96-hour EC_{50}s were completed using appropriate statistical methods (Stephan 1977; Stephan and Rogers 1985; Greene, et al. 1988).

Site-soil eluates were also evaluated with a standard Daphnia magna 48-hour static acute toxicity test. Owing to its geographic distribution and relative ease in laboratory culture systems, D. magna was used in these bioassays. As a representative aquatic macroinvertebrate (e.g., role in aquatic food chains), D. magna complemented the algal bioassay

component completed as part of the toxicity assessment. Briefly, the bioassay used less than 24-hour old D. magna neonates which were exposed to test sample concentrations diluted (volume:volume) to yield logarithmically spaced exposure concentrations ranging from 100% site sample to 0% site sample (dilution water alone). The bioassays were conducted at 22 +/- 2°C (16:8, light:dark); ten D. magna neonates each were placed into triplicate exposure concentrations when the bioassay was started, and at the end of the 48-hour exposure mortality was assessed. Survivorship data was subsequently evaluated to yield LC_{50} estimates (Hamilton, et al. 1977; Stephan 1977), which are reflected as the percent site sample which is associated with 50% mortality.

For these indirect tests, toxicity categories were applied to the data listed in Appendix 1. As such, a class ranking of short-term toxicity estimates was established for the site samples. For purposes of this toxicity assessment, the following four groups of test results were established on the basis of sample dilutions associated with LC_{50} or EC_{50} estimates:

Group 1 = median effect less than or equal to 20% sample dilution

Group 2 = median effect greater than 20%, but less than or equal to 50%

Group 3 = median effect greater than 50%, but less than or equal to 80%

Group 4 = median effect greater than 80% sample dilution.

Routine eluate chemistries. Hardness, salinity, conductivity, total organic carbon (TOC), and pH were determined for each site-soil eluate (Appendix 2), and contributed to toxicity interpretations derived from preliminary spatial statistic analysis. On the work completed for the site toxicity assessment, sample pH was measured prior to toxicity bioassays, and determined whether adjustments were required before toxicity testing was begun. A second pH was subsequently taken upon completion of the bioassays, since pH effects may be quite pertinent to the toxicity information which was collected over the course of exposure.

Spatial statistic tools for ecological assessment. For the preliminary mapping of site chemistry and toxicity data, Geostatistical Environmental Assessment Software (GEOEAS, US EPA 1988b) was used. Variogram analyses and kriging were performed on sample eluate data (Appendix 1 and Appendix 2) using programs VARIO and KRIGE included in the GEOEAS "tool box" of geostatistical methods; by using program CONREC the resulting data files were used to construct preliminary

contour maps for both chemistry and toxicity data generated from soil eluates. Examples of these maps are illustrated in Figures 4, 5, and 6 which summarized representative spatial distribution estimates for selected toxicity and chemical endpoints measured on surface samples.

RESULTS AND DISCUSSION

Toxicity Assessment. Appendix 1 tabulates the comparative toxicity estimates (as LC_{50}s or EC_{50}s) determined for the site-samples. Indirect measures of biological effects were determined on soil eluates and were derived from aquatic toxicity tests (48-hour acute test with D. magna and 96-hour short-term chronic test with S. capricornutum). For the algal and daphnid toxicity tests respectively, Figures 4 and 5 illustrate mappings of site-specific toxicity following variogram analyses and kriging with GEOEAS, while a mapping for a representative soil eluate chemistry (e.g., hardness) is given in Figure 6. Toxicity estimates were based on the toxicity classifications listed above (e.g., Groups 1, 2, 3,and 4) and were derived from the toxicity test results listed in Appendix 1.

Routine Chemistry Support. Appendix 2 lists the results for routine chemical analyses for eluates. In part, these were used for interpreting the biological effects summarized in Appendix 1 (see **Toxicity Assessment**), though the chemistry data routinely included in these toxicity screening tests precludes extensive comments regarding mechanisms of toxicity.

Toxicity evaluation: Correlative Analysis. The sheer number of samples and the heterogeneity in contaminant loads which potentially influence toxicity estimates precludes any definitive statement regarding causality and the toxicity measures derived for the site in these preliminary analyses. The complementary features of the toxicity tests, however, are apparent from a brief overview of the short-term toxicity estimates generated from the work on the site-samples. The 96-hour short-term chronic algal bioassay and the 48-hour acute daphnid toxicity test provided the data base upon which toxicity assessments were developed. For example, when categorized into the toxicity ranks outlined above, the algae and daphnid tests jointly identify 40% of all the site-samples (40 sites x 3 depths plus eight additional soils or 128 samples) as presenting Group 1 endpoints (median effect estimates $\leq$ 20% eluate), which should be considered as potentially highly toxic. These two single-species toxicity tests are quite complementary. Ten samples (10 of 128, or 8%) were jointly flagged by these tests as being highly toxic; the algal and daphnid bioassays respectively identified 27% (35 of 128) and 5% (6 of 128) of site-samples as being in Group 1. "No effect" samples were jointly identified by the algal and daphnid tests in 60% (77 of 128) of the soil eluates evaluated for short-term toxicity. Alone, the 96-hour algal

bioassay identified 35% (44 of 128) of all the samples as being in Group 1, while the daphnid test identified 10%, or 13 of 128 samples as being in this highly toxic category. If one extends this clustering approach to toxicity assessment and includes Groups 1 and 2 as particularly relevant toxicity categories, the algal and daphnid tests respectively identified 50% and 23% of all sample eluates as being highly to moderately toxic. Both identified only 9% of the samples as being in Group 3, while Group 4 (low toxicity, median effect estimates >80%) samples were identified in algal and daphnid tests at 41% and 68%, respectively.

Toxicity evaluation: Spatial distributions. Summary correlative analyses could be drawn for the toxicity assessments at various depths, but Figures 4 and 5 amply illustrate a preliminary toxicity mapping which considers the spatial distribution of toxicity within two surface dimensions for both algae and daphnid. Figure 6 illustrates two distribution maps for surface soil-eluates tested with algae

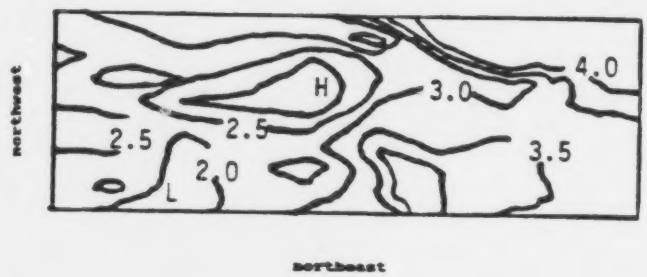

Figure 4. Spatial distribution of toxicity indicated by the short-term algal test and illustrated on toxicity contour map generated by CONREC program in GEOEAS for surface samples [Group 4 toxicity category ($EC_{50}s$ > 80%); Group 3 toxicity category (50% < $EC_{50}s$ ≤ 80%); Group 2 toxicity category (20% < $EC_{50}s$ ≤ 50%); Group 1 toxicity category (0% < $EC_{50}s$ ≤ 20%)]. H = highest toxicity location; L = lowest toxicity location. Reference area unspecified.

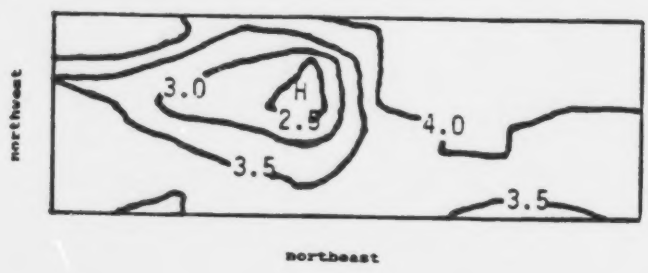

Figure 5. Spatial distribution of toxicity indicated by the daphnid toxicity test and illustrated on toxicity contour map generated by CONREC program in GEOEAS for surface samples [Group 4 toxicity category ($LC_{50}s$ > 80%); Group 3 toxicity category (50% < $LC_{50}s$ ≤ 80%); Group 2 toxicity category (20% < $LC_{50}s$ ≤ 50%); Group 1 toxicity category (0% < $LC_{50}s$ ≤ 20%)]. H = highest toxicity location; L = lowest toxicity location. Reference area unspecified.

and daphnia. From routine eluate chemistry results (Appendix 2), mappings for each chemistry data set (e.g., eluate hardness and salinity in Figure 6) could be plotted, again using the programs of GEOEAS. The preliminary assessment for spatial correlations between site-chemistry and toxicity data could then be achieved through simple "overlay" techniques, and the linkage between toxicity and eluate chemistry inferred from the coincidence patterns noted between the two mappings. The significance of overlay techniques, however, must be viewed in the context of potential bias associated with the mappings generated through GEOEAS. For example, variogram analysis in GEOEAS relies heavily upon interpretation and "trial and error" computations to derive a variogram model used in kriging (US EPA 1988b); more generally, map overlay techniques present a variety of problems when independently derived maps are compared in a spatial context (Bailey 1988).

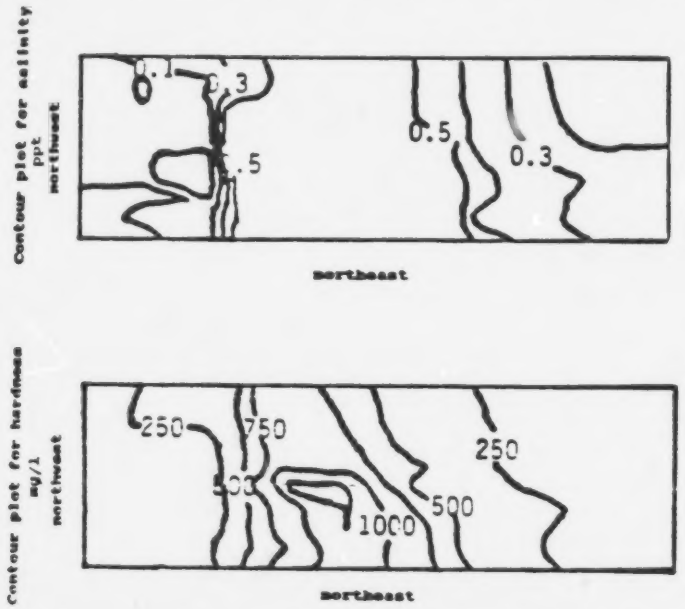

Figure 6. Spatial distribution of eluate chemistry data, e.g., hardness and salinity, illustrated on toxicity contour map generated by CONREC program in GEOEAS for surface samples. Reference area unspecified.

Even without using overlay techniques, distribution maps may be beneficial to toxicity data interpretation nonetheless. For Drake Chemical, even a cursory review of the toxicity data at the various depths presented patterns of toxicity as identified by algae and daphnia toxicity maps. For example, surface point estimators of highly toxic soils (EC_{50}s $\leq$ 20%) were identified by nine algal short-term endpoints which, depending upon closest-neighbor toxicity characteristics, resolves into contour mappings (Figure 4) similar to those illustrated for daphnid toxic responses in Figure 5. The daphnid toxicity rankings derived from the acute tests suggest fewer highly toxic point estimators but the mapping presents a highly coincident toxicity distribution.

Though exploratory by design, these preliminary mappings and toxicity interpretations may bear more relevance to site evaluation than methods related to hypothesis testing in a strictly statistical sense. More rigorous analytical techniques could be applied if additional site information were gathered, and if greater resolution were indicated beyond these short-term screening tests. Reference sites should be critically defined in order to weight toxicity endpoints within the overall site evaluation. Considering the influence that sample integrity bears on toxicity assessment, well-designed field studies should be emphasized regardless of whether laboratory-based or *in situ* toxicity assessments are integral components in the ecological assessment of a site. Through these correlative analyses, preliminary toxicity evaluations may yield information pertinent to site assessments and identify potential topics relevant to site management, e.g., site characterization and effectiveness of remediation efforts (Athey, *et al*. 1987).

SUMMARY: Toxicity evaluations for ecological assessments

As part of the overall ecological assessment for hazardous waste sites, toxicity assessments contribute significantly to site evaluation. These expectations should be clearly defined in the development of the site-specific data quality objectives. Both laboratory and field studies are critical, if the ecological assessment is intended to be an integral part of site evaluation. The following summary points illustrate the value of toxicity assessments in the evaluation process for site:

(1) the waste site presented a characteristically widespread spatial toxicity distribution, though its significance must be evaluated relative to a site-specific reference; the role of well-defined reference sites becomes invaluable in interpreting the extent to which the potential toxicity is expressed in the field;

(2) the algal and daphnid toxicity tests indicated that quantitatively different biological responses occurred at various sampling points (surface and below surface) on the site; the toxicity assessment clearly indicated the potential for high toxicity to occur within ecological contexts, if water soluble constituents from the chemical mixtures in soils were mobilized;

(3) the algal 96-hour short-term chronic test presented EC_{50}s of less than 20% site-sample dilution (Group 1) in 27% of the site-sample eluates; the 48-hour daphnid acute test presented Group 1 responses to 5% of the site-samples; the algal and daphnid tests were complementary and together identified 40% of the site-samples as potentially highly toxic (EC_{50}s of less than 20% site-sample);

(4) vertical migration of toxicity was apparent from the preliminary mapping completed for each of the depths tested, but the significance of the biological responses requires more familiarity with the site reference;

(5) mechanisms of toxicity and causality should not be inferred from preliminary correlative or spatial distribution analyses, nor should toxicity distributions based upon associations between site locations and screening test results infer chemical specific migration without the supporting analytical results.

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Appendix 1. Short-term toxicity estimates (EC_{50}s and LC_{50}s) derived from tests (algal and daphnid) completed on site-sample elustes (sorted by site locations, see also Figure 3).

SAMPLE SITE #	ALGAL EC_{50} (95% C.I.)	DAPHNIA EC_{50} (95% C.I.)
1 surface	NE	NE
middle	1.51 (0.70-3.3)	67.1 (58.4-77.1)
deepest	18.0 (9.2-31.6)	91.2 (87.3-95.3)
2 surface	NE	NE
middle	NE	NE
deepest	NE	NE
3 surface	NE	NE
middle	NE	42.8 (38.0-48.1)
deepest	NE	8.3 (3.7-18.9)
4 surface	1.5 (0.7-3.3)	55.2 (46.7-65.2)
middle	15.1 (9.6-24.6)	66.2 (62.6-70.0)
5 surface	71.7 (17.0-80.0)	NE
middle	NE	NE
deepest	NE	-50.0
6 surface	NE	84.3 (80.4-88.4)
middle	NE	NE
deepest	5.6 (4.2-7.6)	49.0 (37.2-64.6)
7 surface	NE	NE
middle	NE	NE
deepest	67.1 (64.3-69.8)	NE
8 NO SAMPLES COLLECTED		
9 surface	-40.0	
middle	1.1 (0.3-3.9)	16.6 (10.4-26.40
deepest	32.7 (22.9-47.9)	43.9 (36.5-52.9)
10 surface	17.88 (0.0-74.1)	80.5 (76.0-85.3)
middle	NE	NE
deepest	NE	NE
11 surface	NE	NE
middle	NE	NE
deepest	5.5 (1.0-39.8)	NE
12 surface	NE	-30.0
middle	20.8 (4.5-80.0)	NE
deepest	16.7 (6.3-80.0)	-16.7
13 surface	NE	NE
middle	21.6 (11.0-42.2)	NE
deepest	15.9 (4.0-63.0)	NE
14 surface	NE	95.9 (90.2-100.0)
middle	43.8 (23.1-80.0)	NE
deepest	NE	NE
15 NO SAMPLES COLLECTED		
16 surface	NE	
middle	6.3 (1.1-35.5)	NE
deepest	NE	-20.0
17 surface	NE	NE
middle	37.0 (0.7-80.0)	NE
deepest	NE	NE
18 NO SAMPLES COLLECTED		
19 NO SAMPLES COLLECTED		
20 surface	NE	
middle	NE	50.7 (45.3-55.3)
deepest	NE	NE
21 surface	1.0 (0.03-39.8)	NE
middle	8.0 (1.6-39.8)	89.8 (88.6-91.1)
deepest	0.4 (0.01-20.0)	92.8 (89.6-96.1)
22 surface	32.9 (23.4-46.0)	87.4 (82.7-92.4)
middle	18.0 (10.7-31.6)	72.9 (63.8-83.2)
deepest	66.2 (25.1-80.0)	2.2 (1.8-2.8)
23 NO SAMPLES COLLECTED		NE
24 surface	0.7 (0.2-3.2)	
middle	50.4 (16.2-80.0)	22.0 (18.9-25.4)
deepest	NE	-53.0
25 surface	NE	-40.0
middle	NE	NE
deepest	NE	NE
26 surface	4.5 (0.01-80.0)	NE
middle	31.1 (5.0-80.0)	NE
deepest	NE	46.6 (41.1-52.8)
27 surface	14.2 (5.6-22.4)	NE
middle	1.6 (0.6-4.4)	91.4 (89.4-93.5)
deepest	5.8 1.7-19.7)	45.0 (30.6-66.1)
28 surface	NE	NE
middle	8.1 (2.6-25.1)	NE
deepest	NE	NE
29 NO SAMPLES COLLECTED		NE
30 surface	33.9 (0.0-80.0)	
middle	41.9 (28.5-61.7)	39.3 (33.9-45.4)
deepest	7.6 (2.9-18.2)	67.9 (64.4-71.7)
31 surface	10.2 (3.9-26.3)	21.7 (17.9-26.2)
middle	11.4 (3.2-39.8)	22.0 (18.1-26.7)
deepest	2.4 (0.3-20.0)	2.2 (1.8-2.7)
32 surface	NE	6.8 (5.6-8.4)
middle	6.6 (2.3-19.1)	NE
deepest	0.7 (0.04-14.1)	4.4 (3.4-5.7)
33 surface	72.1 (43.6-80.0)	2.9 (2.0-4.2)
middle	NE	93.9 (90.0-97.3)
deepest	8.8 (2.5-30.2)	NE
34 surface	NE	43.0 (39.9-46.4)
middle	NE	NE
deepest	NE	NE
35 NO SAMPLES COLLECTED		NE
36 NO SAMPLES COLLECTED		
37 surface	71.7 (66.8-76.9)	
middle	NE	NE
deepest	4.3 (1.5-12.6)	NE
38 surface	NE	8.6 (7.2-10.3)
middle	11.1 (5.8-20.9)	97.1 (97.1-100)
deepest	43.8 (30.3-61.7)	21.4 (17.0-26.8)
39 surface	NE	5.4 (4.1-7.1)
middle	7.2 (1.0-51.9)	NE
deepest	7.9 (2.5-21.9)	-10.0
		NE

SAMPLE SITE #		ALGAL EC_{50} (95% C.I.)	DAPHNIA EC_{50} (95% C.I.)
40	surface	34.2 (5.2-80.0)	NE
	middle	74.8 (9.9-80.0)	NE
	deepest	NE	NE
41	NO SAMPLES COLLECTED		
42	NO SAMPLES COLLECTED		
43	NO SAMPLES COLLECTED		
44	surface	NE	NE
	middle	77.9 (18.2-80.0)	-47.0
	deepest	46.5 (0.0-80.0)	NE
45	surface	37.9 (3.7-80.0)	NE
	middle	73.5 (60.6-80.0)	92.8 (86.4-99.7)
	deepest	65.3 (20.8-80.0)	55.0 (47.7-63.3)
46	surface	NE	NE
	middle	NE	79.6 (74.3-85.2)
	deepest	NE	75.3 (67.5-84.1)
47	surface	29.0 (0.0-80.0)	NE
	middle	12.0 (2.9-50.0)	51.7 (42.6-62.7)
	deepest	56.1 (1.9-80.0)	72.8 (58.8-90.1)
48	surface	8.6 (2.5-29.5)	71.2 (50.0-100.0)
	middle	19.9 (7.6-52.5)	33.7 (27.8-40.8)
	deepest	-50.0	90.2 (84.9-95.8)
49	surface	7.5 (3.1-17.4)	-40.0
	middle	50.3 (29.0-87.1)	71.1 (63.5-79.5)
	deepest	5.0 (2.5-10.0)	87.8 (85.0-90.7)
50	surface	NE	NE
	middle	17.0 (4.3-67.6)	NE
	deepest	11.7 (6.5-20.4)	NE
51	surface	NE	NE
	middle	-40.0	NE
	deepest	NE	-20.0

[1] Reports listed as negative percents reflect mortality or extent of inhibition observed at highest concentration tested (algae, 80%; Daphnia, 100%). 95 % C.I. = 95% confidence interval about point estimate.

[2] If EC_{50} estimates are extrapolations and not interpolations, projections exceed highest (or lowest) concentrations tested and no precision estimates are possible; median effect estimates should be evaluated as relative measures.

[3] NE = no effect.

Appendix 2. Chemical analysis completed for site-samples received from the Drake Chemical site. Water quality characteristics (conductivity, uS/cm; salinity, ppt; TOC (=total organic carbon), mg/l; hardness, mg/L) completed on eluates prepared from site-soils. Samples sorted by laboratory identification number; sample location listed in Final Technical Report for Drake Chemical site available from NSI Technology Services Corporation, U.S. EPA, ERL-Corvallis, Oregon.

CHEMISTRY NUMBER	SOURCE CODE	COND. (uS)	SALINITY (ppt)	TOC (ppm)	HARDNESS	INIT. pH	FINAL pH
44000	LE	1925.0	1.271	226.40	759.80	9.5	9.4
44001	LE	475.0	0.214	8.10	94.60	6.50	6.50
44002	LE	860.0	0.568	24.40	110.55	5.40	6.50
44100	DE	2475.0	1.634	31.30	918.70	9.90	9.80
44101	DE	2550.0	1.683	116.00	1581.85	6.90	7.00
44102	DE	2470.0	1.630	105.60	1301.04	7.50	7.50
44103	DE	3150.0	2.079	19.70	1625.26	6.80	6.10
44104	DE	2900.0	1.914	88.20	1487.64	6.70	6.30
44105	DE	2770.0	1.828	52.40	1039.75	7.10	7.20
44106	DE	2650.0	1.749	49.90	1704.18	10.00	9.00
44107	DE	2900.0	1.914	135.70	2392.87	8.40	8.30
44108	DE	2250.0	2.211	186.80	1141.41	7.10	7.50
45101	DE	978.0	0.645	81.20	502.21	6.9	7
45113	DE	630.0	0.416	21.90	145.59	6.00	6.90
45114	DE	1890.0	1.247	37.30	222.91	5.40	6.10
45119	DE	862.0	0.569	19.10	340.16	7.20	7.30
46000	LE	338.0	0.222	9.10	170.54	7.80	7.80
46001	LE	1115.0	0.736	10.00	404.92	4.60	6.20
46002	LE	448.0	0.296	8.19	202.78	8.30	8.20
46003	LE	800.0	0.528	24.60	284.38	7.10	7.10
46004	LE	371.0	0.246	12.70	63.70	5.70	6.20
46005	LE	448.0	0.296	11.80	247.40	7.30	7.60
46007	LE	130.5	0.086	6.40	15.12	5.20	6.50
46008	LE	207.6	0.137	11.80	104.40	8.00	8.00
46009	LE	102.5	0.068	6.40	34.66	6.60	6.50
46010	LE	124.5	0.082	2.70	46.55	7.10	7.20
46011	LE	705.0	0.465	23.70	161.21	5.20	6.20
46012	LE	272.0	0.180	4.60	18.18	4.80	6.50
46013	LE	538.0	0.355	11.80	82.15	5.00	6.40
46014	LE	520.0	0.343	10.30	212.42	5.00	6.30
46015	LE	324.0	0.214	11.80	17.29	5.60	6.50
46016	LE	478.0	0.315	20.90	45.94	4.60	6.20
46017	LE	148.0	0.096	6.40	55.71	6.60	7.10
46018	LE	650.0	0.416	20.90	192.82	4.50	6.40
46019	LE	375.0	0.248	24.60	108.59	4.70	6.20
46020	LE	1900.0	1.254	5.60	805.17	4.10	7.20
46021	LE	1370.0	0.904	14.70	221.60	4.00	6.60
46022	LE	219.0	0.145	4.20	110.05	7.40	7.90
46023	LE	144.0	0.095	4.20	15.81	5.80	6.20
46024	LE	376.0	0.248	2.10	112.51	6.40	6.60
46026	LE	1860.0	1.228	86.10	1060.87	5.50	6.60
46027	LE	875.0	0.578	16.10	304.56	6.60	6.80
46028	LE	1285.0	0.848	6.30	877.14	5.30	6.60
46030	LE	1375.0	0.908	9.10	842.32	5.20	6.40
46100	DE	374.0	0.247	10.90	66.86	6.30	6.50
47000	LE	439.0	0.290	14.70	245.45	7.70	7.80
47002	LE	740.0	0.488	4.90	316.17	6.30	6.40
47006	LE	497.0	0.328	11.90	266.94	7.40	8.00
47007	LE	363.0	0.240	3.50	182.71	7.60	7.50
47008	LE	1233.0	0.814	25.20	627.20	6.90	7.70
47009	LE	730.0	0.482	10.50	109.70	5.80	6.90
47010	LE	630.0	0.416	9.80	331.82	7.40	8.10
47011	LE	1720.0	1.135	18.90	1302.57	6.90	7.60
47012	LE	1080.0	0.713	14.70	335.60	5.10	5.40
47013	LE	1080.0	0.713	22.10	667.47	7.20	8.10
47014	LE	930.0	0.614	95.90	404.02	6.60	7.00
47015	LE	770.0	0.508	4.90	361.26	8	7.2
47016	LE	290.0	0.191	28.70	35.60	5.5	6.2
47017	LE	302.0	0.199	4.90	43.62	6	6.2
47020	LE	471.0	0.311	12.80	113.04	7.8	7.6
47022	LE	540.0	0.356	12.80	284.85	7.9	7.6
47023	LE	1055.0	0.696	22.30	688.16	6.7	7.4
47024	LE	970.0	0.640	12.80	379.95	5.4	6
47025	LE	800.0	0.528	15.50	129.21	8	7.5
47026	LE	142.0	0.094	14.20	53.46	5.9	6.3
47028	LE	459.0	0.303	3.40	244.76	7.1	7.9
47029	LE	481.0	0.317	8.80	210.02	5.5	6.2
47030	LE	350.0	0.263	11.50	262.51	6.5	7.1
47031	LE	525.0	0.347	8.10	277.56	6.2	7.4
47032	LE	104.0	0.069	8.10	37.04	6.8	6.8
47033	LE	110.0	0.073	15.50	36.89	7.00	6.20
47034	LE	402.0	0.265	12.80	22.01	6.70	6.60
47035	LE	300.0	0.198	7.40	158.25	7.80	8.10
47036	LE	94.0	0.062	2.00	28.46	4.90	6.30
47037	LE	89.8	0.059	2.00	25.33	5.00	6.20
47100	LE	990.0	0.653	59.40	394.28	7.50	7.70
47101	DE	385.0	0.254	83.00	152.50	7.10	7.00
47102	DE	462.0	0.305	40.50	189.74	7.10	7.00
47104	DE	1170.0	0.772	15.50	624.54	7.50	7.70
47107	LE	740.0	0.488	14.20	325.76	5.80	7.10
47108	LE	479.0	0.315	0.00	210.10	7.80	7.80
47109	LE	638.0	0.421	0.00	126.46	6.20	6.50
47110	DE	82.0	0.054	0.00	24.87	7.00	6.90
47111	DE	57.0	0.038	0.00	11.22	6.70	6.80
47112	LE	550.0	0.363	34.40	85.80	6.40	6.20
47113	LE	141.0	0.093	0.00	29.99	5.50	6.60
47114	LE	222.0	0.147	14.20	48.04	5.70	6.70
48000	LE	345.0	0.228	21.80	174.48	8.00	7.90
48001	LE	142.0	0.094	5.46	33.32	6.30	6.40
48002	LE	145.0	0.096	6.40	50.72	6.70	6.70
48003	LE	244.0	0.161	11.60	109.57	6.90	7.70
48004	LE	168.0	0.111	0.20	62.65	6.20	6.60
48005	LE	362.0	0.240	8.19	176.87	7.60	7.70
48006	LE	321.0	0.212	10.00	145.66	7.70	7.80
48007	LE	425.0	0.281	11.80	201.25	7.50	7.70
48100	DE	195.0	0.129	0.00	35.24	5.10	6.20